GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: February 13, 1978

Project Title: Design of Solar Hot Water System, Solar Makeup Water Preheat System and Solar Building Heating System for the Aircraft Corrosion Control Facility Robins AFB

Project No: A-2081

Project Director: Mr. Charles A. Murphy

Sponsor: Robert and Company Associates

Agreement Period: From 11/14/77 Until 1/31/78

Type Agreement: Letter of Intent, dtd. 11/18/77 (to assist on Corps of Engineers, Robins AFB, Georgia, Solar System for Aircraft Corrosion Control Facility Project)

Amount: $7,925

Reports Required: Final Report

Sponsor Contact Person (s):

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(thru OCA)

Defense Priority Rating: None

Assigned to: ASL/SEMTD (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
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Project File (OCA)
Project Code (GTRI)
Other

-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

no action
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SPONSORED PROJECT TERMINATION

Date: February 24, 1978

roject Title: Design of Solar Hot Water System, Solar Makeup Water Preheat System and Solar Building Heating System for the Aircraft Corrosion Control Facility Robins AFB

roject No: A-2081

roject Director: Mr. Charles A. Murphy

ponsor: Robert and Company Associates

ffective Termination Date: 1/31/78

learance of Accounting Charges: 1/31/78

rant/Contract Closeout Actions Remaining:

NONE

- Final Invoice and Closing Documents
- Final Fiscal Report
- Final Report of Inventions
- Govt. Property Inventory & Related Certificate
- Classified Material Certificate
- Other ______

gned to: Applied Sciences Laboratory (School/Laboratory)

BOUND

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Procurement Office	Project Code (GTRI)
Security Coordinator (OCA)	Other ______
Reports Coordinator (OCA)	

…-4 (3/76)

CONCEPTUAL DESIGN

FINAL REPORT

January 1978

To

Robert and Company Associates

By

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Solar Energy and Materials Technology Division
225 North Avenue, N. W.
Atlanta, Georgia 30332

DESIGN OF SOLAR HOT WATER SYSTEM, SOLAR MAKEUP WATER PREHEAT SYSTEM AND SOLAR BUILDING HEATING SYSTEM FOR THE AIRCRAFT CORROSION CONTROL FACILITY ROBINS AFB

Principal Investigator:

James M. Akridge
Senior Research Engineer

Program Manager:

Charles A. Murphy
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ABSTRACT

Solar collection and energy storage systems were analyzed and sized for three potential applications at Robins Air Force Base at Warner Robins, Georgia. The three applications considered under this program were: (1) a "Solar Hot Water System" for supplying aircraft wash water at 140^{o} F for the Aircraft Corrosion Control Facility; (2) a "Solar Makeup Water System," for supplying solar preheated water for the Aircraft Corrosion Control Facility boiler; and (3) a "Solar Building Heating System" for heating the Aircraft Corrosion Control Facility.

Three high performance flat plate solar collectors (PPG, Revere, and Halstead Mitchell) and two high performance nontracking concentrating collectors (KTA and General Electric) were examined for each potential application. Additionally, the effect of reflector augmentation of the flat plate collectors was examined.

1. TECHNICAL APPROACH

The three potential applications had widely differing load profiles and/or temperature limitations resulting in each system having to be considered separately with a design for each system being required to meet its specific requirements.

1.1 INSOLATION DATA

1.1.1 Heating System Requirements

Thirty year normal degree day data for Macon available from NOAA (1) were used to establish heating loads. Ten year average monthly insolation data for Griffin available in ASHRAE GRP-170 (2) were modified using the procedure developed by Liu and Jordan (3) (4) to develop average monthly insolation data for Macon. These data were developed for several different collector tilts. A 49 degree collector tilt was selected as being best for the heating application. These data were then used with a Georgia Tech F-chart programmable calculated program* to size the facility solar heating system. Column 4 (49 degree tilt) in Table II-A in Appendix A gives the monthly average data which was constructed and used for sizing the Solar Heating Systems.

When one is using clear sky data such as presented in ASHRAE GRP-170 and used here to determine hourly solar insolation, modifying factors which

*Note: Duffie and Beckman (5) have developed an emperical method of designing solar heating systems using ten or twenty year average monthly degree days and average monthly insolation values. The Duffie-Beckman method called F-chart has been checked extensively for locations where hourly data tapes are available and verified with performance data from solar heating systems currently operating.

correct for clearness factors less than 1, for cloud cover, for industrial contaminants, and for location altitude must be used. Although ASHRAE GRP-170 presents correction factors which can be interpolated for Macon, ASHRAE GRP-170 recommends that multiyear meteorological data be used for improved accuracy if available. Since measured NOAA ten year $\overline{K}_T$ data for Griffin are presented in ASHRAE GRP-170, these were used to "correct" the Macon clear sky data. $\overline{K}_T$ combines all of the correction factors into one correction factor. Due to the relatively closeness of Macon and Griffin, $\overline{K}_T$ should vary little between the two locations. This approach should give much more accurate data than one would have obtained through the use of all the interpolated correction factors.

1.1.2 Makeup and Hot Water Systems

The load profile for the Solar Hot Water System and the Solar Makeup Water System are so drastically different from that of a typical heating system, the F-chart method of analysis was considered unsuitable as a reliable method of analysis for these systems. It was apparent that synthesized data would have to be developed for Warner Robins so that a programable calculator simulation of the system could be performed.

Since both the Solar Hot Water System and the Solar Makeup Water Preheat System have almost constant monthly load demands and the insolation is highly variable throughout the year, the collector tilt was optimized to give the most uniform collector profile throughout the year. This requires synthesizing data for each different collector tilt considered. Average monthly solar insolation data were developed for many different collector tilts using the Liu-Jordan method used to develop the data for the heating system. Table II-A in Appendix A presents the synthesized average monthly data for Macon for eight different collector tilts. Analysis of the data showed that a collector tilt of 56 degrees gives the least standard deviation from month to month, i.e., maximum month-to-month system performance consistency.

A collector tilt of 56 degrees was chosen as being optimum for the Solar Makeup Water Preheat System because the collector area requirements were minimal and a 56 degree tilt gave the least month-to-month deviation in system output. Average hourly data were developed using hourly clear sky data from ASHRE GRP-170 in combination with NOAA ten year average cloudiness factors for Griffin and the methods of Liu-Jordan. Table III-A in Appendix A presents the average hourly insolation data developed for Macon for a collector tilt of 56 degrees.

Since it appeared that it might be desirable to place the collectors on the roof of the Aircraft Corrosion Control Facility and that the roof area was marginal for the Solar Hot Water System, the analysis was extended to determine the collector tilt which would permit the maximum number of collectors to be installed onto the facility roof without decreasing the energy collected per ft^2 in December, the most critical month. It was determined that a collector tilt of 49 degrees would permit 20 rows of 77 inches nominal length collectors; the collector tilt would have to be decreased to 35 degrees to permit the installation of one additional row. A collector tilt of 49 degrees decreased the insolation per ft^2 from that of the 56 degree optimum tilt less than 1 percent, while a collector tilt of 35 degrees decreased the insolation by 5 percent. This analysis showed that a collector tilt of 49 degrees permitted the greatest quantity of energy to be collected from the space available on the facility roof while keeping the collector area at a minimum. This tilt did not affect month-to-month consistency significantly.

1.2 SYSTEM SIMULATION

The data in Tables III-A and IV-A were then used with programable calculator simulation programs which simulated both the Solar Hot Water System and the Solar Makeup Water Systems. These programs did an energy balance on each system.* This permitted the energy collected, energy used, collector efficiency, energy lost and system storage temperatures to be determined for each hour of the seven day cycle. Since the objective in both the Solar Hot Water System and the Solar Makeup Water System was to supply 100 percent of the requirements or as large a fraction as possible, December became the critical month because of the lower insolation values during this period. A seven day December cycle was run on each of the three flat plate collectors and on the nontracking concentrating KTA collector to determine system performance. The General Electric collector was not analyzed by the simulation because of the high collector cost and the lack of certified test data. Table I-A in Appendix A gives the weight, size, effective area ratio, efficiency equation and cost of each of the collectors.

1.3 REFLECTOR AUGMENTATION

Reflector augmentation of flat plate collectors is not considered practical for multiple row collectors except for summer augmentation (not

*Note: Piping losses were neglected as were the energy requirements for the transient morning start-up. A "point" analysis of these determined that they would have an effect of reducing system output by a maximum of 5 percent.

applicable to applications considered herein) because the addition of the reflector causes a significant increase in collector spacing for a relatively minor increase in energy collected per square foot of collector area. Figure 1 compares a non-augmented collector array with an augmented array with the reflector sized to optimize the insolation on the collector at solar noon on the winter solstice, the day needing the most augmentation. A horizontal reflector 36 inches long was determined to be optimum for solar noon at the winter solstice for a collector tilt of 49 degrees. The reflector increases the collector spacing by 36 inches which decreases the number of collectors that can be put on the Aircraft Corrosion Control Facility by 20 percent. If one assumes a reflector reflectivity of 75 percent, the energy available at solar noon at the winter solstice per ft^2 of collector possibly can be increased by 13.3 percent through the use of reflectors. The word possibly is used here because the reflected energy hits the collector at a very shallow angle (15.1 degrees maximum) and much of this energy may be reflected by the collector glazing which cannot be evaluated using available data. Not only does the quantity of reflected energy decrease either side of winter solstice, but the angle at which the reflected energy strikes the collector also decreases. When one combines the maximum possible increase in insolation through reflector augmentation with the decrease in collector areas necessary when using reflector augmentation, one finds that only

$$\frac{\text{Energy Collected With Reflector}}{\text{Energy Collected Without Reflector}} = \frac{16 \text{ Rows} \times 1.133}{20 \text{ Rows}} \times 100 = 90.6\%$$

90.6 percent as much energy can be collected for a given array area with a reflector augmented collector as with non-augmented collectors.

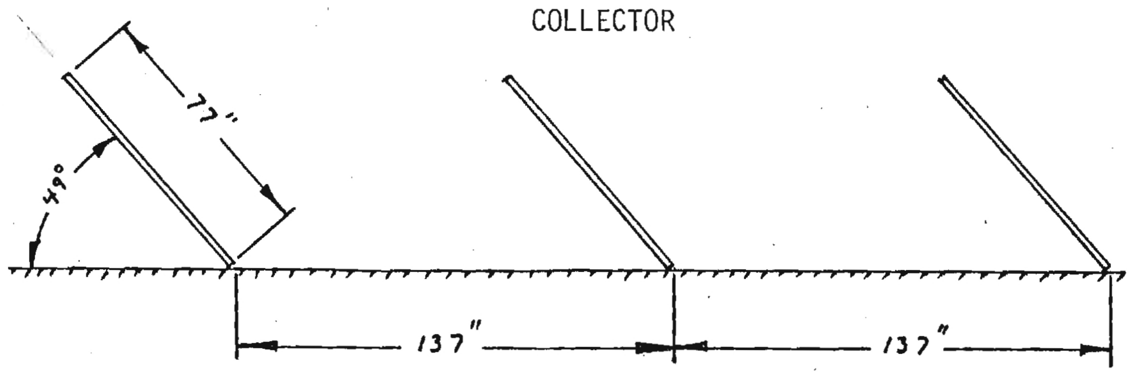

Figure 1A. Non-Reflector Augmented Solar Array.

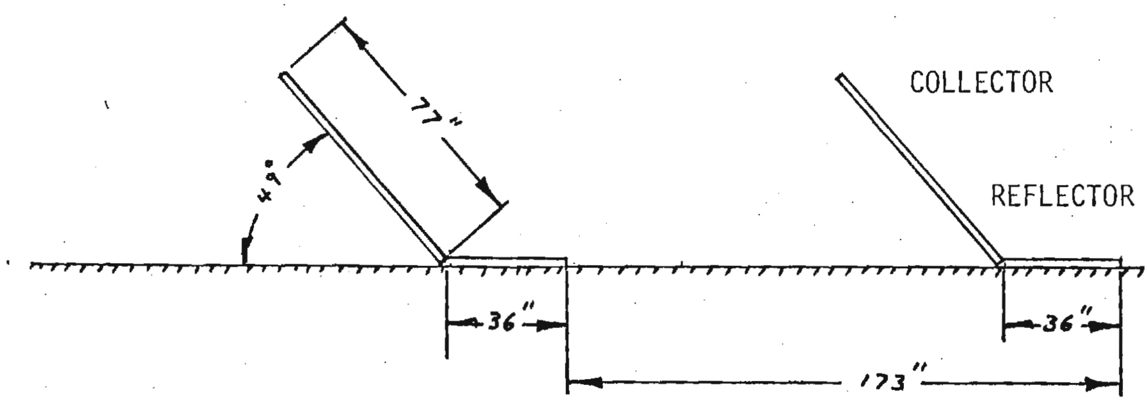

Figure 1B. Reflector Augmented Solar Array.

It is clear from the above why reflectors are not used to augment flat plate collectors in the winter. They not only contribute very little, but they also require a substantial increase in area devoted to the collector system which impacts the costs of the overall system.

2. DISCUSSION OF RESULTS

2.1 GENERAL

Table I summarizes the various collector's performance in the Solar Hot Water System. This table shows the KTA collector to be slightly better than the three flat plate collectors with the PPG collector slightly better than the Revere and the Halstead Mitchell collector less efficient than the others. KTA recently made a change in their collector design and does not yet have certified data to support the performance of the new design. The analysis given here used the data given for the older KTA design. The PPG and Revere collectors are so near in performance, it would be difficult to make a selection based on performance alone.

TABLE I

COMPARISON OF COLLECTOR AREA REQUIRED TO MEET 97.3 PERCENT OF DECEMBER SOLAR HOT WATER REQUIREMENTS

Manufacturer	Model	Type	Area Required (ft^2)
1. PPG	C529	Flat Plate	17,114
2. Revere	Sun-Aid DG-WW-BC	Flat Plate	18,060
3. Halstead-Mitchell	Sunceiver 35775	Flat Plate	23,360
4. KTA	KTA 4-85	Concentrating Non-Tracking	16,307
5. General Electric	TC-100	Concentrating Non-Tracking	Undetermined

2.2 HOT WATER SYSTEM

Figures 2-5 show the storage temperature profile of the Solar Hot Water System throughout an average week in December, March, June, and September. Tables II and III summarizes the system performance by month. Table II shows that 17,114 ft^2 of the PPG collector is capable of supplying 100 percent of the system requirements for all months except December, when it delivers 97.3 percent of the December needs. Table III shows that 16,307 ft^2 of the KTA collector will match the PPG collector's performance.

2.3 MAKEUP WATER SYSTEM

Figures 6-9 show the storage temperature profile of the Solar Makeup Water System throughout an average week in December, March, June, and September. Tables IV and V summarize the system performance by month. Table IV shows that 1806 ft^2 of the PPG collector can deliver from 64 to 88 percent of the system requirements, while Table V shows that 1675 ft^2 of the KTA collector can deliver 66 to 90 percent of the system requirements.

2.4 BUILDING HEAT SYSTEM

Tables VI and VII summarize the Solar Heating System performance by month. These tables emphasize the penalty one pays for a load profile which varies widely from month to month. This is compounded by the highest demands being in those months when the least solar energy is available. The Solar Building Heating System was sized to provide approximately 60 percent of the annual Building Heating Requirements. Monthly percentage vary from a low of 44.8 percent in December to a high of 100 percent for March through October.

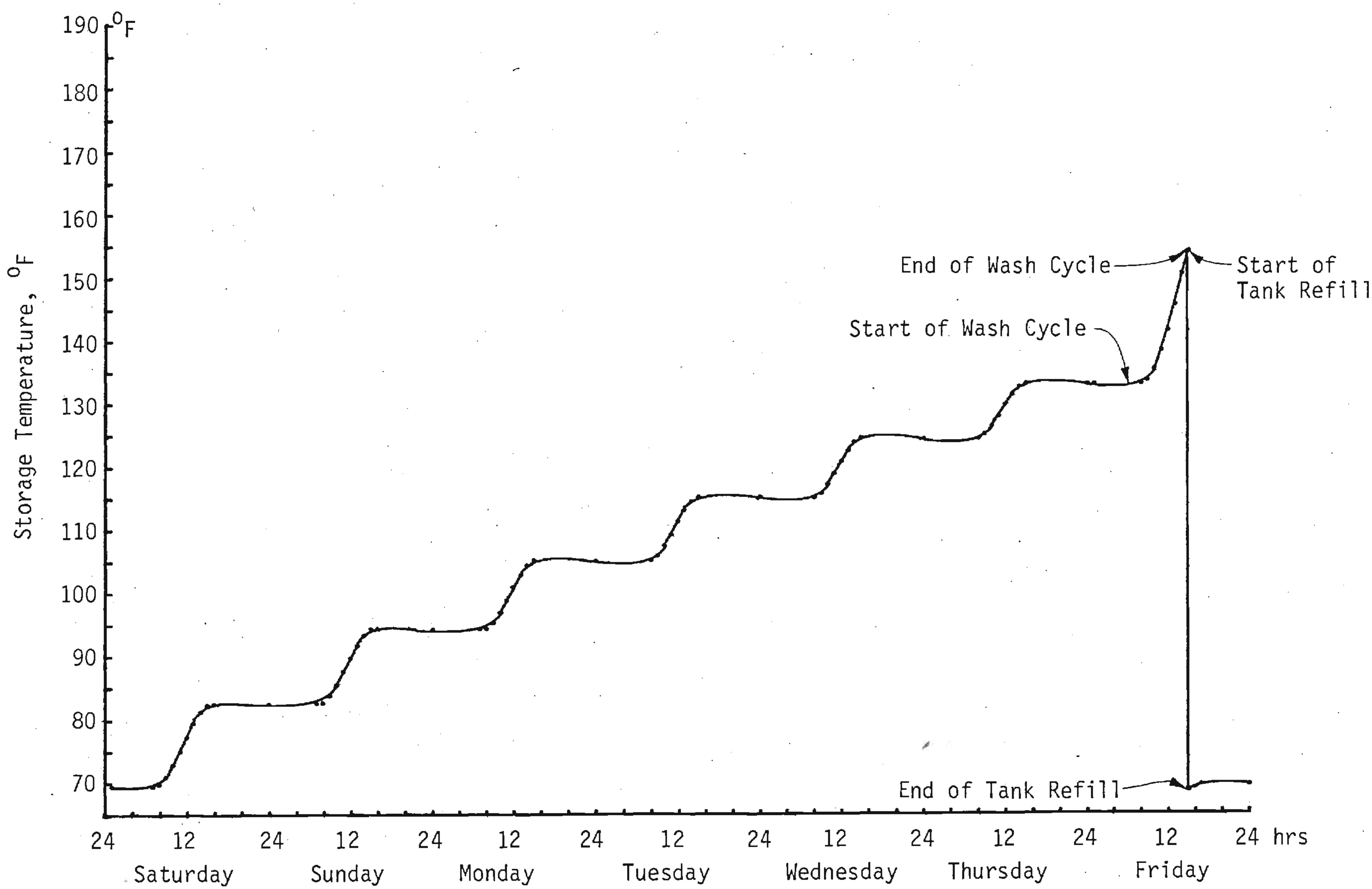

Figure 2. Solar Hot Water System Storage Temperature - Average Week in December.

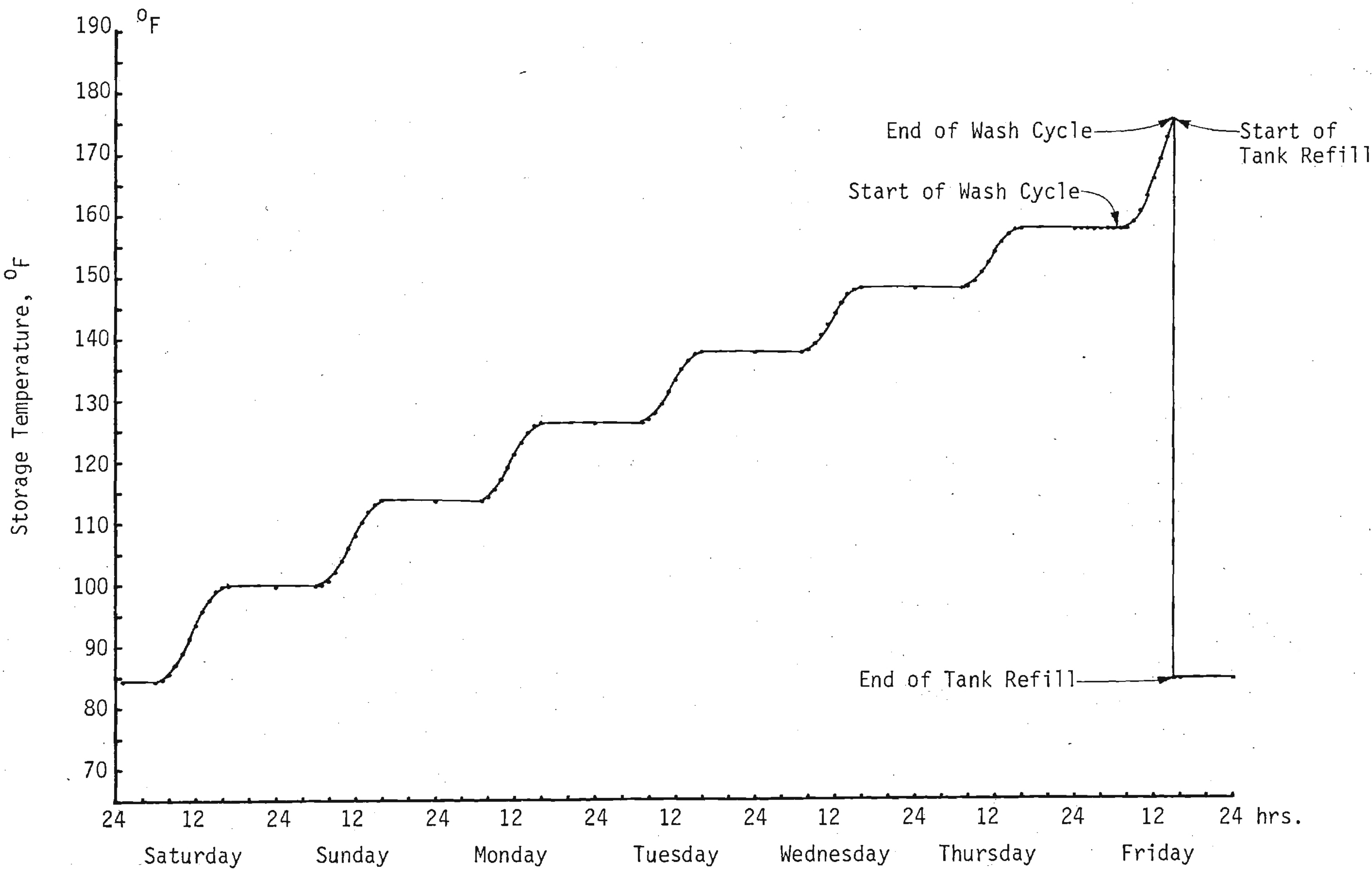

Figure 3. Solar Hot Water System Storage Temperature - Average Week in March.

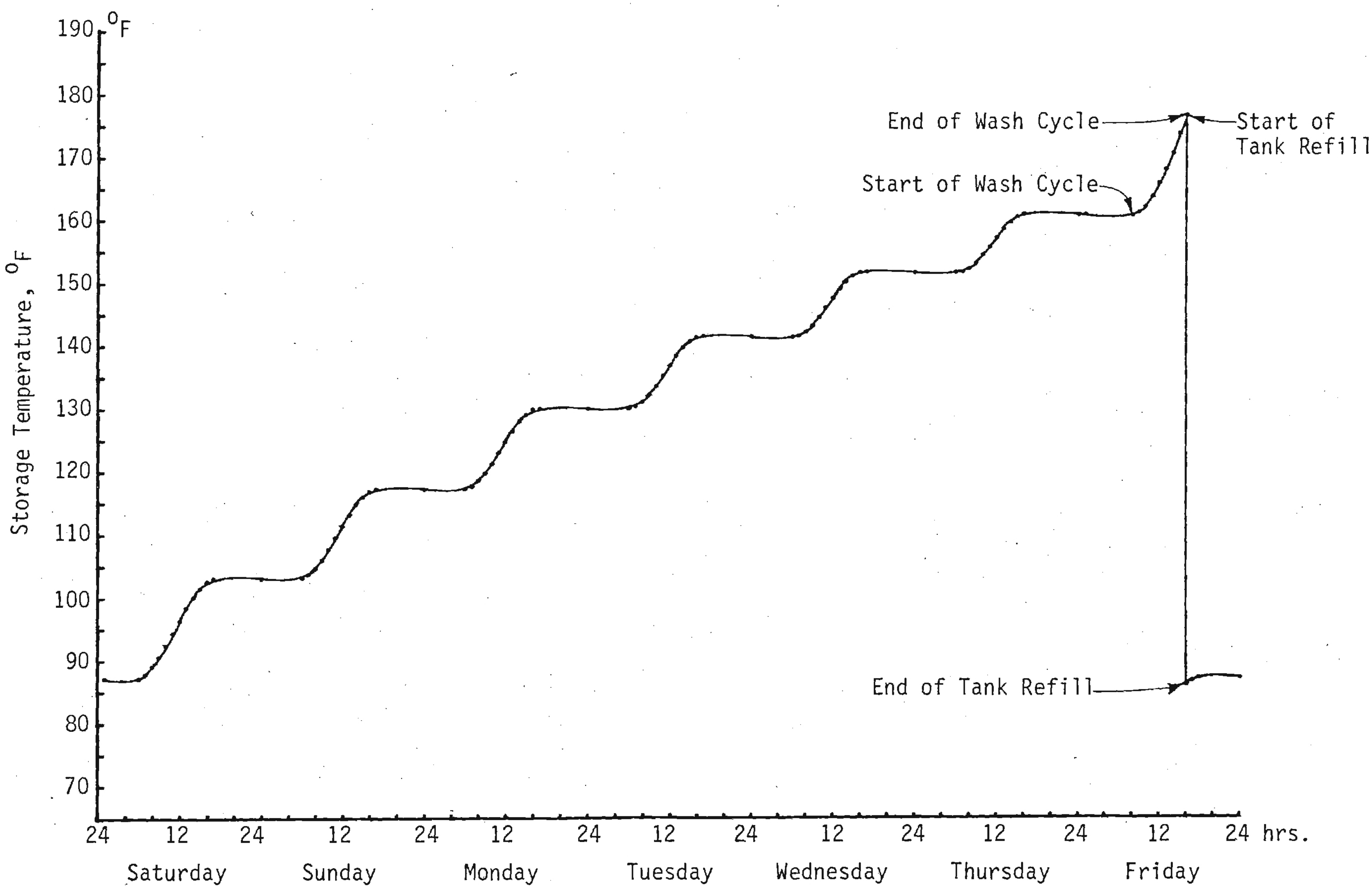

Figure 4. Solar Hot Water System Storage Temperature - Average Week in June.

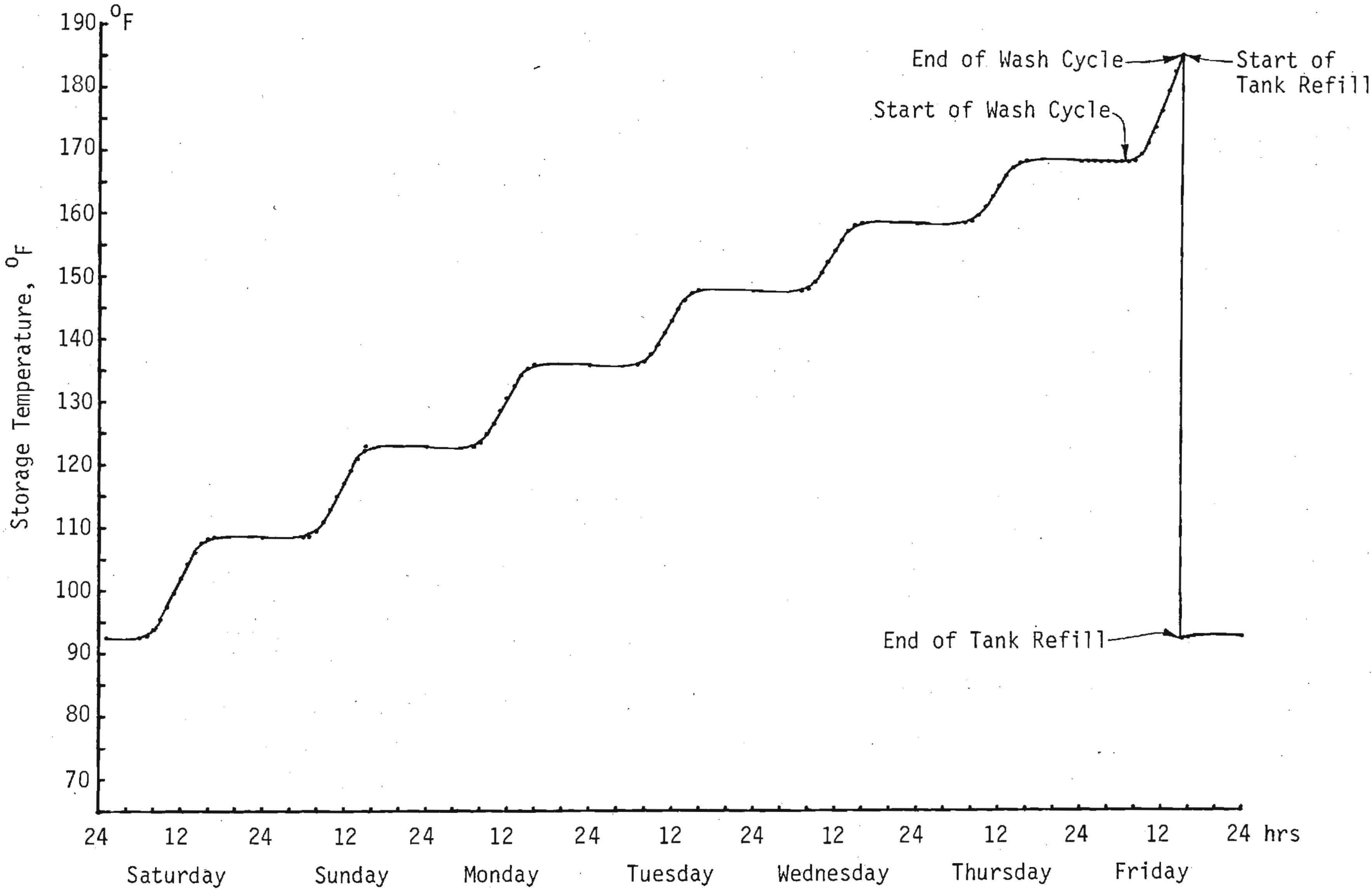

Figure 5. Solar Hot Water System Storage Temperature - Average Week in September.

TABLE II

SOLAR COLLECTOR SYSTEM SUMMARY, FLAT PLATE

SYSTEM Solar Hot Water System

COLLECTOR AREA 17,114 ft^2 (effective)

STORAGE VOLUME 125,000 gallons

COLLECTOR FLOW RATE 580 gpm (water-ethylene glycol)

STORAGE FLOW RATE 1060 gpm

AREA HEAT EXCHANGER 1019 ft^2

LOCAL LATITUDE 32.67^o N

COLLECTION TILT 49^o

PERFORMANCE

MONTH	AVERAGE ENERGY COLLECTED/MONTH Btu/month	PERCENT OF SYSTEM DEMAND (1)
January	339.6×10^6	100
February	306.7×10^6	100
March	339.6×10^6	100
April	328.6×10^6	100
May	339.6×10^6	100
June	328.6×10^6	100
July	339.6×10^6	100
August	339.6×10^6	100
Sept	328.6×10^6	100
Oct	339.6×10^6	100
Nov	328.6×10^6	100
Dec	331.8×10^6	97.7

ENERGY COLLECTED PER YEAR 3.99×10^9 Btu

PERCENT OF YEARLY DEMAND 99.8%

ENERGY COLLECTED PER FT^2 OF COLLECTOR 233×10^3 $Btu/ft^2/yr$

COLLECTOR USED FOR EVALUATION PPG Model C529

COLLECTOR PERFORMANCE EQUATION $\eta = 0.74 - 0.62\ P$

$$P = \frac{T_{in} - T_{amb}}{I}$$

(1) System was sized using average solar insolation data. Overcast days exceeding three days per week will occur and will reduce solar percentage below 100 percent. On very clear week excess energy will be available.

TABLE III

SOLAR COLLECTOR SYSTEM SUMMARY, CONCENTRATING, NON-TRACKING

SYSTEM Solar Hot Water System

COLLECTOR AREA 16,307 ft^2 (effective)

STORAGE VOLUME 125,000 gallons

COLLECTOR FLOW RATE 580 gpm (water-ethylene glycol)

STORAGE FLOW RATE 1060 gpm

AREA HEAT EXCHANGER 1019 ft^2

LOCAL LATITUDE 32.67° N

COLLECTION TILT 49°

PERFORMANCE

MONTH	AVERAGE ENERGY COLLECTED/MONTH Btu/month	PERCENT OF SYSTEM DEMAND (1)
January	339.6×10^6	100
February	306.7×10^6	100
March	339.6×10^6	100
April	328.6×10^6	100
May	339.6×10^6	100
June	328.6×10^6	100
July	339.6×10^6	100
August	339.6×10^6	100
Sept	328.6×10^6	100
Oct	329.6×10^6	100
Nov	328.6×10^6	100
Dec	331.8×10^6	97.7

ENERGY COLLECTED PER YEAR 3.99×10^9 Btu

PERCENT OF YEARLY DEMAND 99.8%

ENERGY COLLECTED PER FT^2 OF COLLECTOR 244.7×10^3 $Btu/ft^2/yr$

COLLECTOR USED FOR EVALUATION KTA 4-85

COLLECTOR PERFORMANCE EQUATION $\eta = 0.643 - 0.3136P$

$$P = \frac{T_{in} - T_{amb}}{I}$$

(1) System was sized using average solar insolation data. Overcast days exceeding three days per week will occur and will reduce solar percentage below 100 percent. On very clear week excess energy will be available.

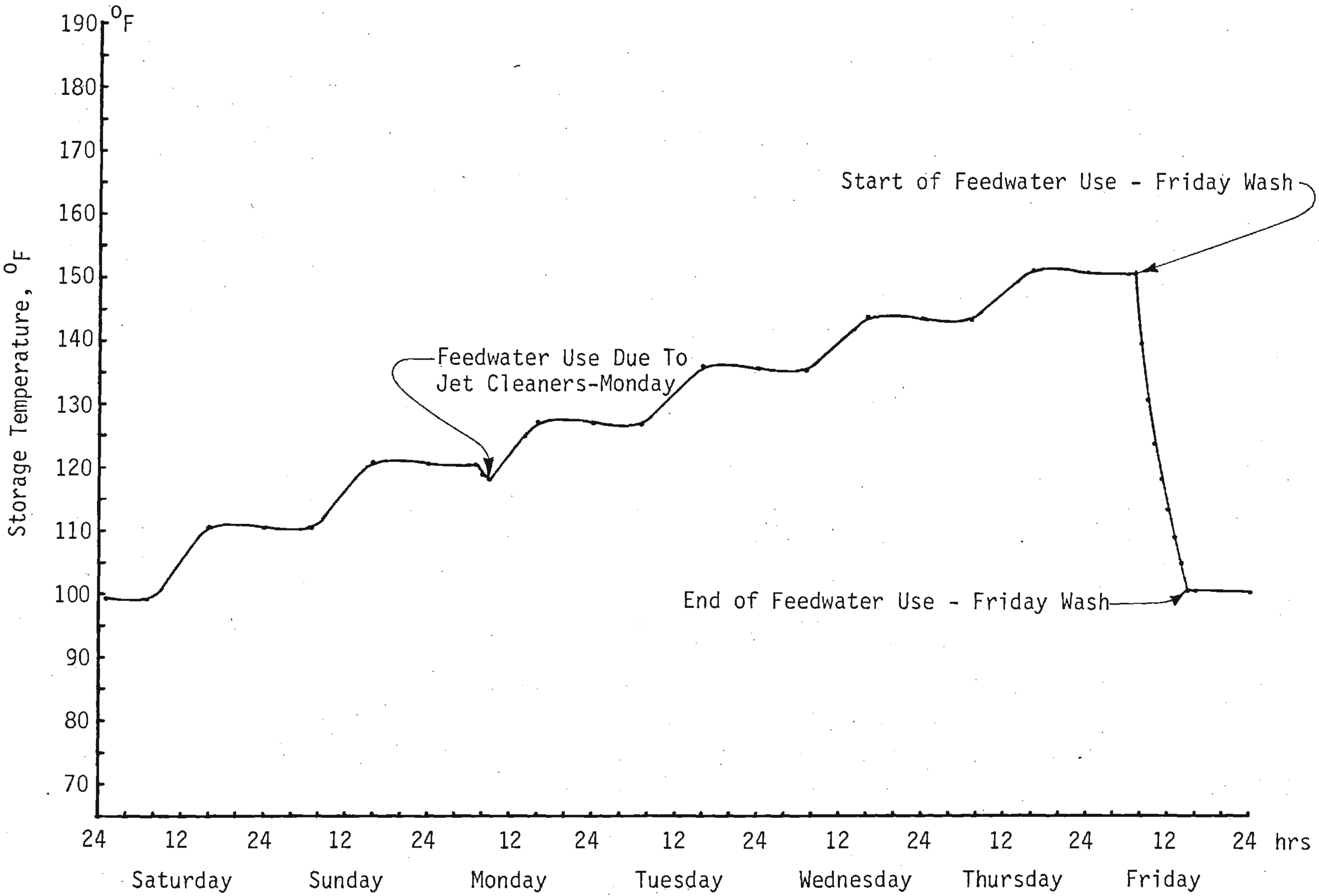

Figure 6. Solar Feedwater Preheat System Storage Temperature - Average Week in December.

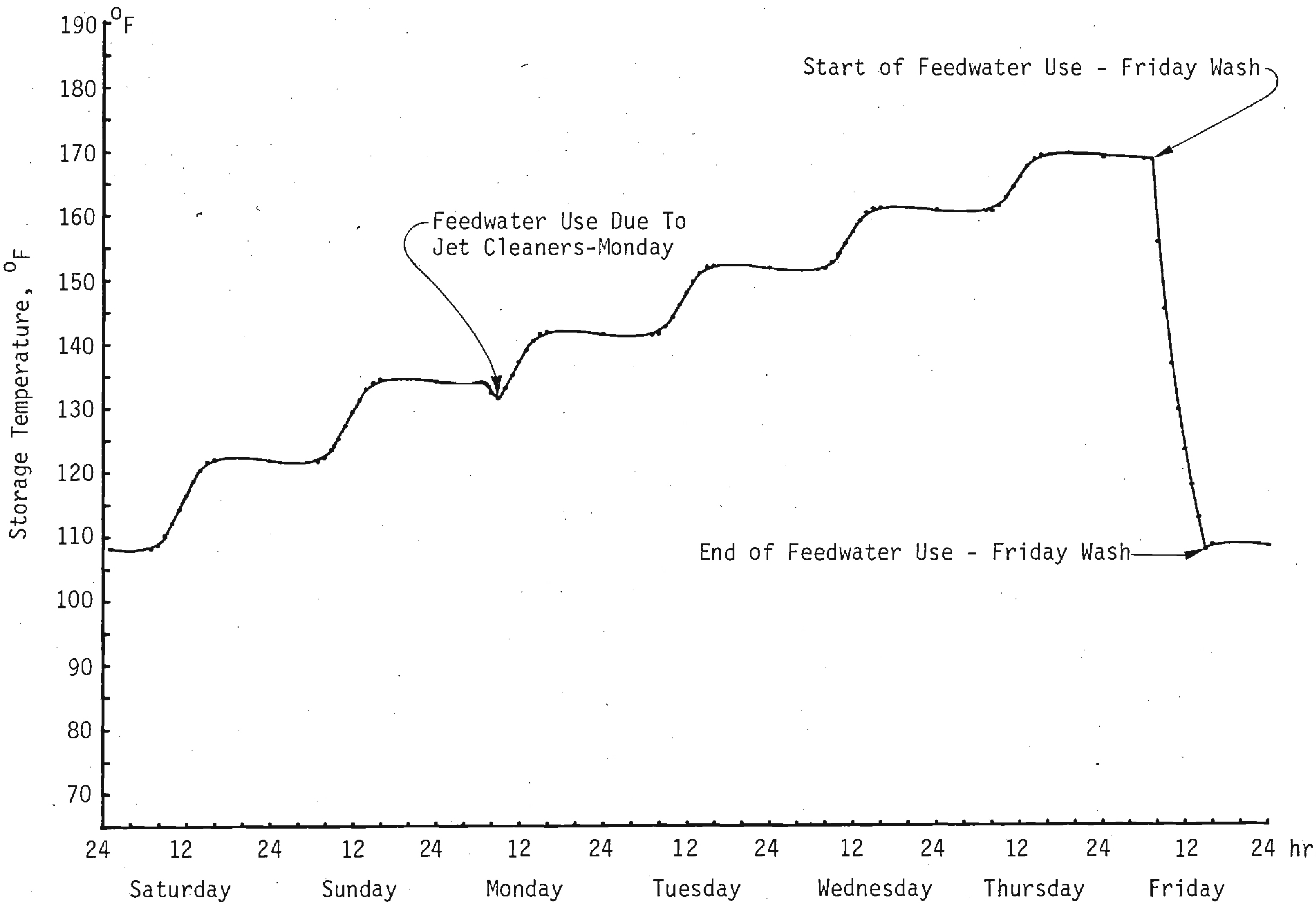

Figure 7. Solar Feedwater Preheat System Storage Temperature - Average Week in March.

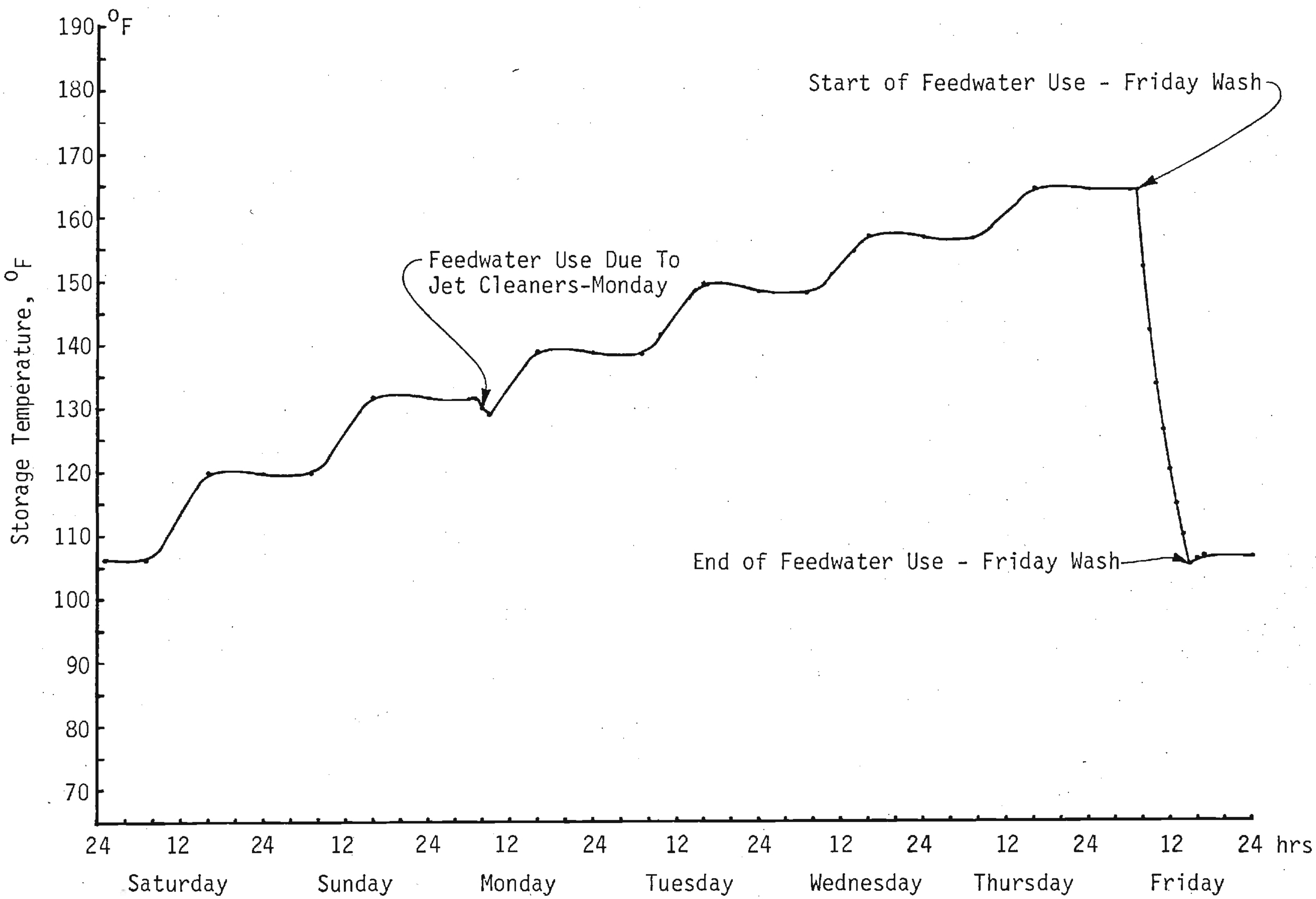

Figure 8. Solar Feedwater Preheat System Storage Temperature - Average Week in June.

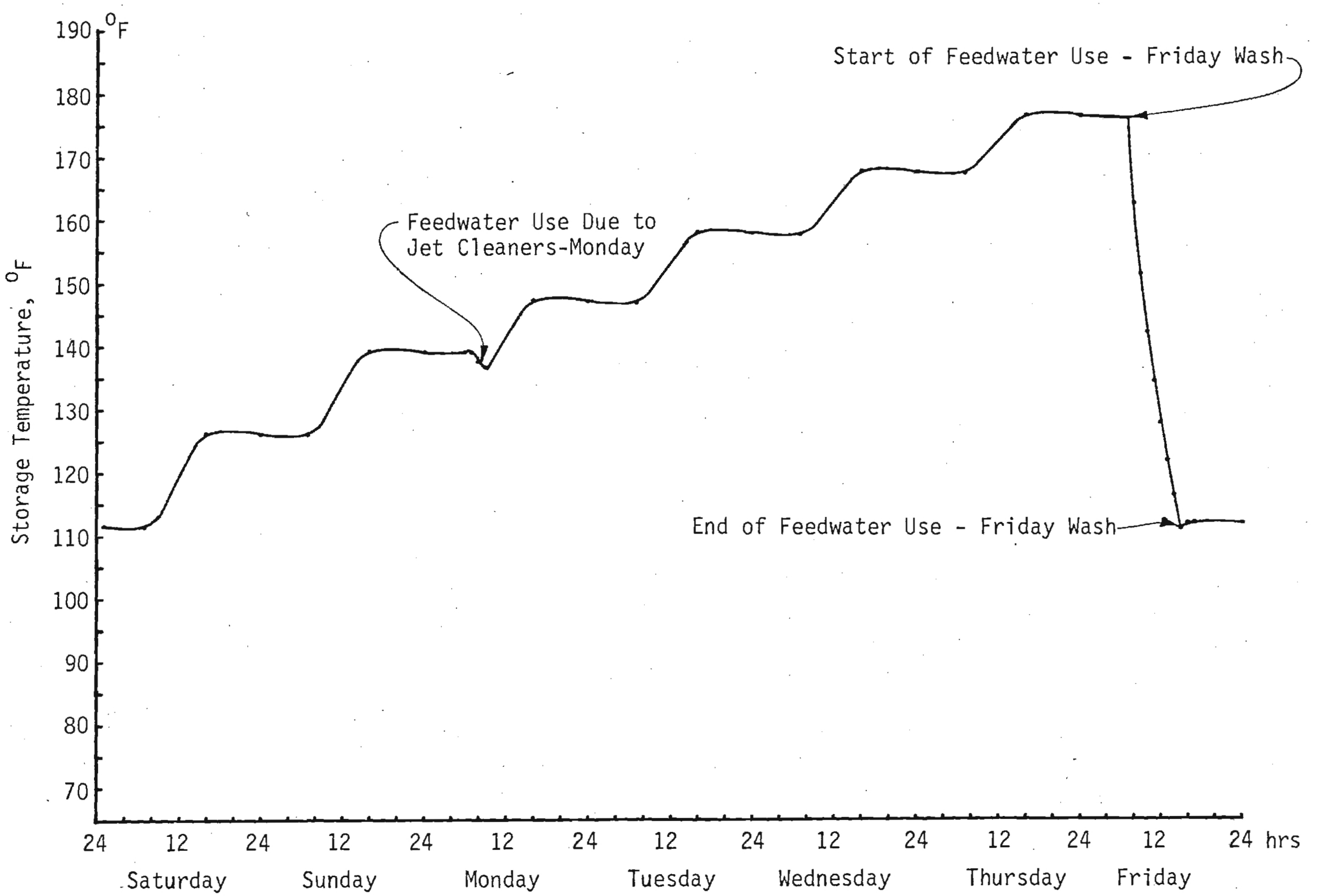

Figure 9. Solar Feedwater Preheat System Storage Temperature - Average week in September.

TABLE IV

SOLAR COLLECTOR SYSTEM SUMMARY, FLAT PLATE

SYSTEM Solar Feedwater Preheat

COLLECTOR AREA 1806 ft^2 (effective)

STORAGE VOLUME 11,600 gallons

COLLECTOR FLOW RATE 60 gpm (water-ethylene glycol)

STORAGE FLOW RATE 106 gpm

AREA HEAT EXCHANGER 100 ft^2

LOCAL LATITUDE 32.67°

COLLECTION TILT 56°

PERFORMANCE

MONTH	AVERAGE ENERGY COLLECTED/MONTH Btu/month	PERCENT OF SYSTEM DEMAND
January	31.8×10^6	68.9
February	29.5×10^6	72.0
March	33.2×10^6	76.4
April	32.4×10^6	79.2
May	32.5×10^6	76.9
June	30.0×10^6	73.3
July	30.9×10^6	73.3
August	34.7×10^6	82.3
Sept	33.5×10^6	81.8
Oct	37.2×10^6	87.8
Nov	34.5×10^6	81.4
Dec	29.5×10^6	64.1

ENERGY COLLECTED PER YEAR 389.9×10^6 Btu

PERCENT OF YEARLY DEMAND 76.4

ENERGY COLLECTED PER FT^2 OF COLLECTOR 216×10^3 Btu/ft^2/yr

COLLECTOR USED FOR EVALUATION PPG Model C529

COLLECTOR PERFORMANCE EQUATION $\eta = 0.74 - 0.62\ P$

$$P = \frac{T_{in} - T_{amb}}{I}$$

(1) Demand set by 160° F to deaerator and 60° F supply.
(2) System temperature was allowed to float to a maximum of 180° F.

TABLE V

SOLAR COLLECTOR SYSTEM SUMMARY, CONCENTRATING, NON-TRACKING

SYSTEM Solar Feedwater Preheat System

COLLECTOR AREA 1675.6 ft^2 (effective)

STORAGE VOLUME 11,600 gallons

COLLECTOR FLOW RATE 60 gpm (water-ethylene glycol)

STORAGE FLOW RATE 106 gpm

AREA HEAT EXCHANGER 100 ft^2

LOCAL LATITUDE 32.67^0 N

COLLECTION TILT 56^0

PERFORMANCE

MONTH	AVERAGE ENERGY COLLECTED/MONTH Btu/month	PERCENT OF SYSTEM DEMAND
January	32.86×10^6	71.2
February	30.80×10^6	75.2
March	34.54×10^6	79.5
April	33.94×10^6	83.0
May	33.75×10^6	79.9
June	30.94×10^6	75.6
July	31.58×10^6	74.9
August	34.99×10^6	82.8
Sept	34.24×10^6	83.6
Oct	38.13×10^6	90.0
Nov	35.36×10^6	83.4
Dec	30.25×10^6	65.7

ENERGY COLLECTED PER YEAR 401.38×10^6

PERCENT OF YEARLY DEMAND 78.65

ENERGY COLLECTED PER FT^2 OF COLLECTOR 239.5×10^3 $Btu/ft^2/yr$

COLLECTOR USED FOR EVALUATION KTA 4-85

COLLECTOR PERFORMANCE EQUATION $\eta = 0.643 - 0.3136P$

$$P = \frac{T_{in} - T_{amb}}{I}$$

(1) Demand set by 160^0 F to deaerator and 60^0 F supply.

(2) System temperature was allowed to float to a maximum of 180^0 F.

TABLE VI

SOLAR COLLECTOR SYSTEM SUMMARY, FLAT PLATE

SYSTEM Solar Building Heating System

COLLECTOR AREA 15,000 ft^2 (effective)

STORAGE VOLUME 30,000 gallons

COLLECTOR FLOW RATE 500 gpm (water-ethylene glycol)

STORAGE FLOW RATE 880 gpm

AREA HEAT EXCHANGER 834 ft^2

LOCAL LATITUDE 32.67^{o} N

COLLECTION TILT 49^{o}

PERFORMANCE

MONTH	AVERAGE ENERGY COLLECTED/MONTH Btu/month	PERCENT OF SYSTEM DEMAND
January	298×10^6	47.4
February	273×10^6	61.1
March	181×10^6	100.0
April	---	---
May	---	---
June	---	---
July	---	---
August	---	---
Sept	---	---
Oct	---	---
Nov	230×10^6	95.6
Dec	270×10^6	44.8

ENERGY COLLECTED PER YEAR 1.25×10^9 Btu

PERCENT OF YEARLY DEMAND 59.6

ENERGY COLLECTED PER FT^2 OF COLLECTOR 83.3×10^3 $Btu/ft^2/yr$

COLLECTOR USED FOR EVALUATION PPG Model C529

COLLECTOR PERFORMANCE EQUATION $\eta = 0.74 - 0.62\ P$

$$P = \frac{T_{in} - T_{amb}}{I}$$

TABLE VII

SOLAR COLLECTOR SYSTEM SUMMARY, CONCENTRATING, NON-TRACKING

SYSTEM Solar Building Heating System

COLLECTOR AREA 15,000 ft^2 (effective)

STORAGE VOLUME 30,000 gallons

COLLECTOR FLOW RATE 500 gpm (water-ethylene glycol)

STORAGE FLOW RATE 880 gpm

AREA HEAT EXCHANGER 834 ft^2

LOCAL LATITUDE 32.67^{o} N

COLLECTION TILT 49^{o}

PERFORMANCE

MONTH	AVERAGE ENERGY COLLECTED/MONTH Btu/month	PERCENT OF SYSTEM DEMAND
January	289.7×10^6	46.0
February	266.5×10^6	59.6
March	181.0×10^6	100.0
April	---	---
May	---	---
June	---	---
July	---	---
August	---	---
Sept	---	---
Oct	---	---
Nov	233.8×10^6	97.7
Dec	264.3×10^6	43.8

ENERGY COLLECTED PER YEAR 1.235×10^9 Btu

PERCENT OF YEARLY DEMAND 58.8

ENERGY COLLECTED PER FT^2 OF COLLECTOR 82.3×10^3 $Btu/ft^2/yr$

COLLECTOR USED FOR EVALUATION KTA 4-85

COLLECTOR PERFORMANCE EQUATION $\eta = 0.643 - 0.3136P$

$$P = \frac{T_{in} - T_{amb}}{I}$$

3. LIMITATIONS ON ANALYSIS

It must be realized that because of the unavailability of measured insolation data for Macon as well as the unavailability of hourly "typical year" temperatures and insolation for the site, the analysis used average degree day data and synthesized average insolation data. This approach "smoothed" results. A quick visual scan of single year weather tapes for Griffin indicates that very cloudy periods exceeding four days may occur several times during a year. Obviously, the system will not provide 100 percent of the Solar Hot Water System requirements for those weeks with three or four overcast days. It also could supply well over 100 percent of the system needs for those weeks with mostly clear days.

Because of the probability of extended overcast periods exceeding three days, the Solar Building Heating System was sized to supply 60 percent of the annual building heating requirements rather than three days at maximum design conditions. Storage volume was increased to two gallons per ft^2 of collector from the more typical value of one and one-half gallon per ft^2 of collector.

4. POTENTIAL SYSTEM PERFORMANCE IMPROVEMENTS

Careful examination of the data from the Solar Hot Water System reveals that despite the collectors being tilted to 49 degrees, the system can collect substantially more energy than can be used every month except November, December and January. System temperature was allowed to float to levels approaching 180^{0} F during the months with excess energy. This reduces the collector efficiency resulting in a decrease in energy collected until it equals energy requirements.

A far better approach would be to use this increased collection capability to provide makeup water preheat. It appears that a substantial fraction of the makeup water energy requirements could be met during the nine excess energy months. The percentage could be further increased by optimizing collector tilt and storage volume for a combined system. The combined system should cost very little more than the Solar Hot Water System alone and would collect substantially more useful energy.

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APPENDIX A

TABLE I-A

COMPARISON OF COLLECTOR AREAS REQUIRED TO MEET 97.3 PERCENT OF DECEMBER SOLAR HOT WATER SYSTEM REQUIREMENTS

Manufacturer	Model	Efficiency Equation(1)	Size (in)	Effective Area / Gross Area	Weight (lbs)	Cost ($/ft^2)	Area Required (ft^2)
I. Flat Plate (Non Concentrating)							
A. PPG	C529	n=.74-.62P	36x77	0.919	117	13.90	17,114
B. Revere	Sun-Aid DG-WW-BC	n=.719-.654P	36x77	0.919	152	15.45	18,060
C. Halstead-Mitchell	35775	n=.783-1.085P	36x77	0.919	135	11.51	22,360
II. Flat Plate (Concentrating, Non-Tracking)							
A. KTA	KTA4-85	n=0.643-0.3136P	63½x87½	0.867	88.2	10.95	16,307
B. General Electric	TC-100	Not Available (2)	48x53	0.850(EST)	62.0	20.00	N.A.

(1) $P = \frac{\text{Tin-Tamb}}{I}$

(2) Performance data given in literature is based on direct insolation rather total insolation. Based on overall design, the G. E. Collector should be less efficient at temperatures below approximately 180° F and more efficient at temperatures above 180° F.

TABLE II-A

AVERAGE DAILY SOLAR INSOLATION ON TILTED SURFACE FOR MACON, GEORGIA, 32.67° N. LATITUDE[1,2]

Month	Tilt Angle From Horizontal, Degrees							
	0	33	47	49	52	55	56	60
Jan	904	1352	1429	1434	1439	1440	1440	1434
Feb	1139	1503	1532	1530	1523	1513	1509	1488
March	1441	1675	1633	1620	1598	1572	1563	1521
April	1910	1880	1709	1677	1627	1573	1554	1476
May	2154	1899	1640	1597	1530	1461	1437	1338
June	2161	1810	1528	1483	1413	1340	1316	1215
July	2048	1751	1494	1452	1387	1320	1297	1204
August	1950	1822	1619	1583	1528	1469	1448	1364
Sept	1573	1683	1587	1567	1533	1497	1483	1427
Oct	1328	1676	1682	1675	1662	1645	1639	1608
Nov	1018	1487	1561	1565	1567	1566	1565	1555
Dec	793	1226	1307	1313	1319	1322	1322	1320

[1] Data computed for 21st day of each month using Liu and Jordan Method.

[2] In Btu/ft^2-day.

TABLE III-A

AVERAGE TOTAL HOURLY SOLAR INSOLATION ON A TILTED SURFACE FOR MACON, GEORGIA[1]

	32.67° N Latitude - Tilted 56° from Horizontal											
Solar Time	Jan[2]	Feb[2]	Mar[2]	Apr[2]	May[2]	Jun[2]	Jul[2]	Aug[2]	Sep[2]	Oct[2]	Nov[2]	Dec[2]
7	0	19.3	40.5	56.6	61.3	59.5	55.9	53.0	37.5	18.8	0	0
8	62.7	83.2	96.8	104.0	100.3	93.1	90.8	97.2	91.3	89.1	67.3	47.2
9	132.0	141.0	145.5	144.8	133.5	122.0	120.6	134.6	138.4	153.5	144.4	117.5
10	186.8	185.7	183.8	175.7	158.7	144.2	143.0	163.2	174.4	202.0	203.2	179.7
11	221.5	213.7	207.8	195.4	174.8	158.2	157.6	181.9	197.2	233.6	241.1	207.4
12	223.8	233.4	215.3	202.0	180.5	162.9	162.3	188.1	204.6	244.5	253.4	218.9
1	221.5	213.7	207.8	195.4	174.8	158.2	157.6	181.9	197.2	233.6	241.1	207.4
2	186.8	185.7	183.8	175.7	158.7	144.2	143.0	163.2	174.4	202.0	203.2	179.7
3	132.0	141.0	145.5	144.8	133.5	122.0	120.6	134.6	138.4	153.5	144.4	117.5
4	62.7	83.2	96.8	104.0	100.3	93.1	90.8	97.2	91.3	89.1	67.3	47.2
5	0	19.3	40.5	56.6	61.3	59.5	55.9	53.0	37.5	18.8	0	0
Total Daily	1430	1509	1563	1554	1437	1316	1297	1448	1483	1639	1563	1322

[1]Data computed for 21st day of each month using Liu and Jordan Method.

[2]In Btu/ft^2-hr.

TABLE IV-A

AVERAGE TOTAL HOURLY SOLAR INSOLATION ON A TILTED SURFACE FOR MACON, GEORGIA

Solar Time	Jan[2]	Feb[2]	Mar[2]	Apr[2]	May[2]	Jun[2]	Jul[2]	Aug[2]	Sep[2]	Oct[2]	Nov[2]	Dec[2]
	32.67° N Latitude - Tilted 49° from Horizontal											
7	0	19.5	42.0	60.3	67.2	67.0	60.0	57.2	39.7	19.2	0	0
8	62.4	84.4	100.2	110.8	109.9	104.8	97.6	105.0	96.5	91.1	67.3	46.9
9	131.5	143.0	150.7	154.2	146.3	137.4	129.6	145.4	146.3	156.9	144.4	116.7
10	186.0	188.0	190.4	187.2	174.0	162.4	153.7	176.3	184.4	206.4	203.2	178.4
11	220.6	216.7	215.2	208.2	191.5	178.1	169.4	196.5	308.5	238.8	241.1	205.9
12	232.8	226.4	223.0	215.2	197.8	183.3	174.5	203.2	216.3	250.0	253.4	217.3
1	220.6	216.7	215.2	208.2	191.5	178.1	169.4	196.5	208.5	238.8	241.1	205.9
2	186.0	188.0	190.4	187.2	174.0	162.4	153.7	176.3	184.4	206.4	203.2	178.4
3	131.5	143.0	150.7	154.2	146.3	137.4	129.6	145.5	146.3	156.9	144.4	116.7
4	62.4	84.4	100.2	110.8	109.9	104.8	97.6	105.0	96.5	91.1	67.3	46.9
5	0	19.5	42.0	60.3	67.2	67.0	60.0	57.2	39.7	19.2	0	0
Total Daily	1434	1530	1620	1677	1597	1483	1452	1583	1567	1675	1565	1313

[1] Data computed for 21st day of each month using Liu and Jordan Method.

[2] In Btu/ft^2-hr.